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Development of low noise and high speed SWIR receivers

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Outline

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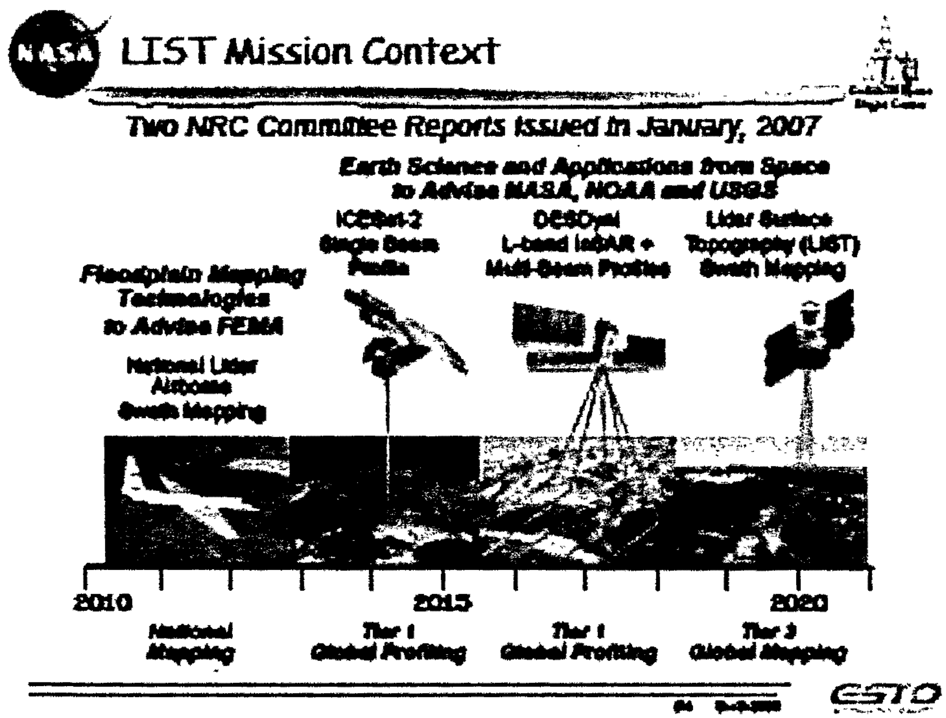
- Motivation
- Receiver Requirements
- Gen.1 photoreceiver design and performance
- Gen. 2 design and receiver development
  - I^2E low excess noise APD design
- Summary

Motivation

- Low-noise high speed receivers operating in the 1-1.5 micron wavelength region are needed for future NASA LADAR imaging applications
- Currently LADAR receivers use Si APD detectors with sensitivity as low as 40 fW/Hz$^{1/2}$ for many NASA applications
  - Si detectors are limited to only in the visible spectrum



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Receiver Requirements

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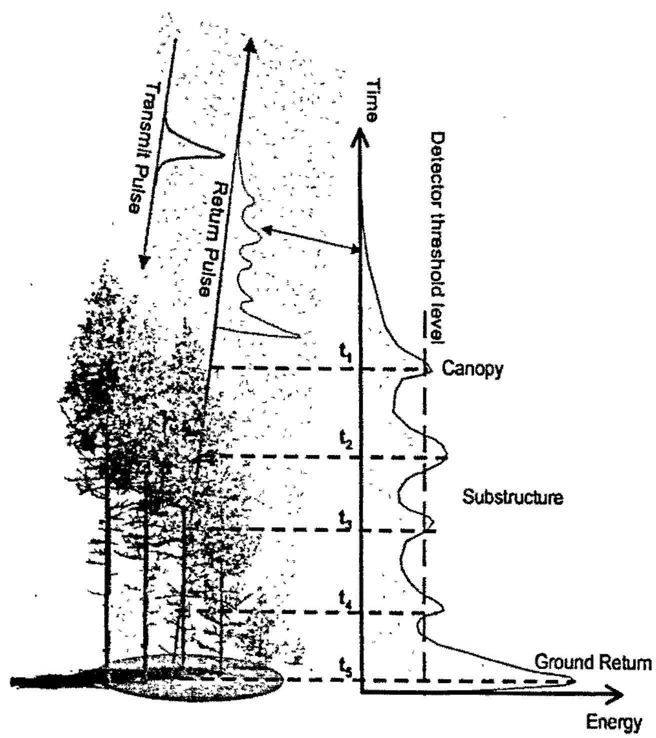
Goal:

Generation 1: 1.06μm APD receivers with 200 μm aperture, sensitivity < 100 fW/Hz$^{1/2}$ @ a bandwidth of 140 MHz

Generation 2: 1.06μm APD receivers with sensitivity < 300 fW/Hz$^{1/2}$ @ bandwidth of 1GHz



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Noise Equivalent Power Analysis

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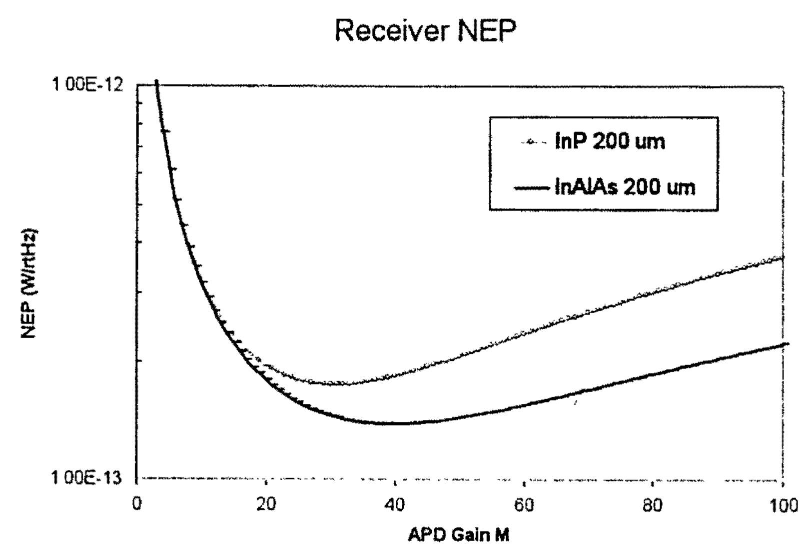
- APD + TIA Amp NEP

$$NEP = \frac{1}{Rsp}\left[2qI_dF + \frac{\alpha^2}{M^2}\right]^{1/2}$$

$$F = kM + (2 - \frac{1}{M})(1-k)$$

where R_{sp} is the APD unity gain responsivity, M is the APD optical gain, F is the APD excess noise factor, k is the ratio of the hole and electron ionization coefficients, α is the TIA noise current density.

- Two critical parameters to reduce NEP
  - Excess noise factor k
  - TIA noise current density α



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Gen. 1 Photoreceiver Design

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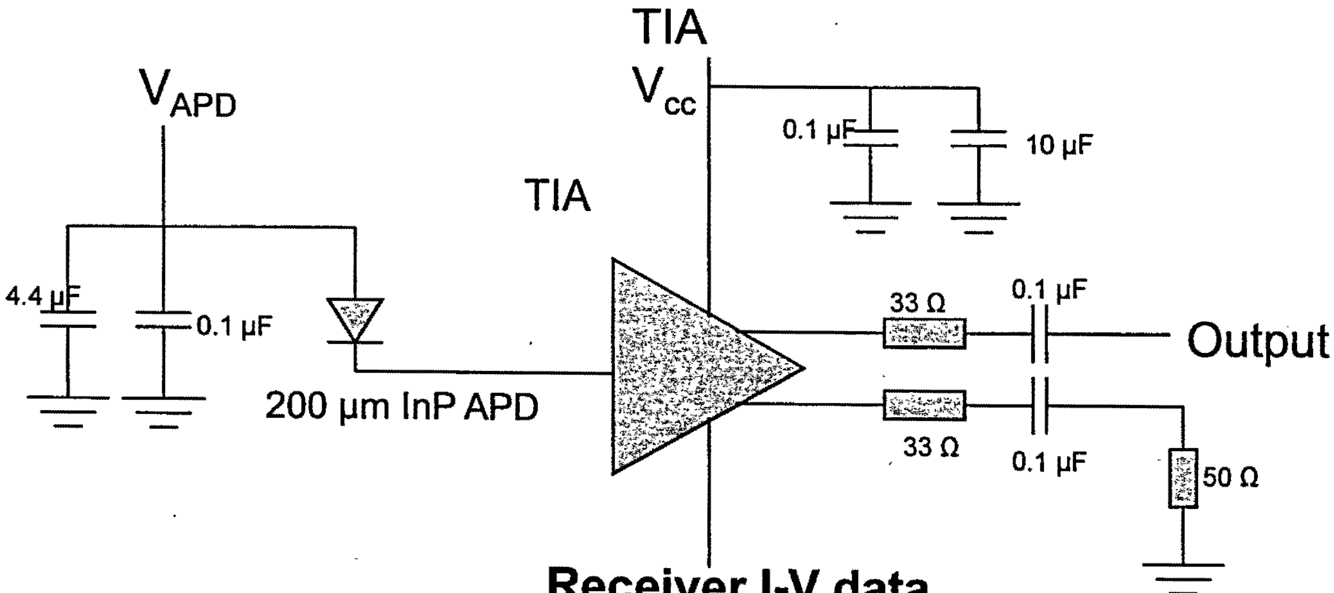
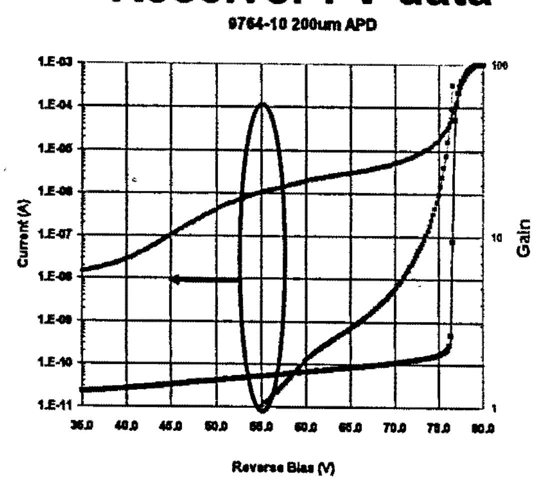
- 200 µm InP APD
- Low noise TIA , SA5211 1.8 pA/Hz$^{1/2}$
- An integrated TEC cooler and a AD590 temperature sensor chip



Receiver I-V data



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Gen. 1 Receiver Bandwidth

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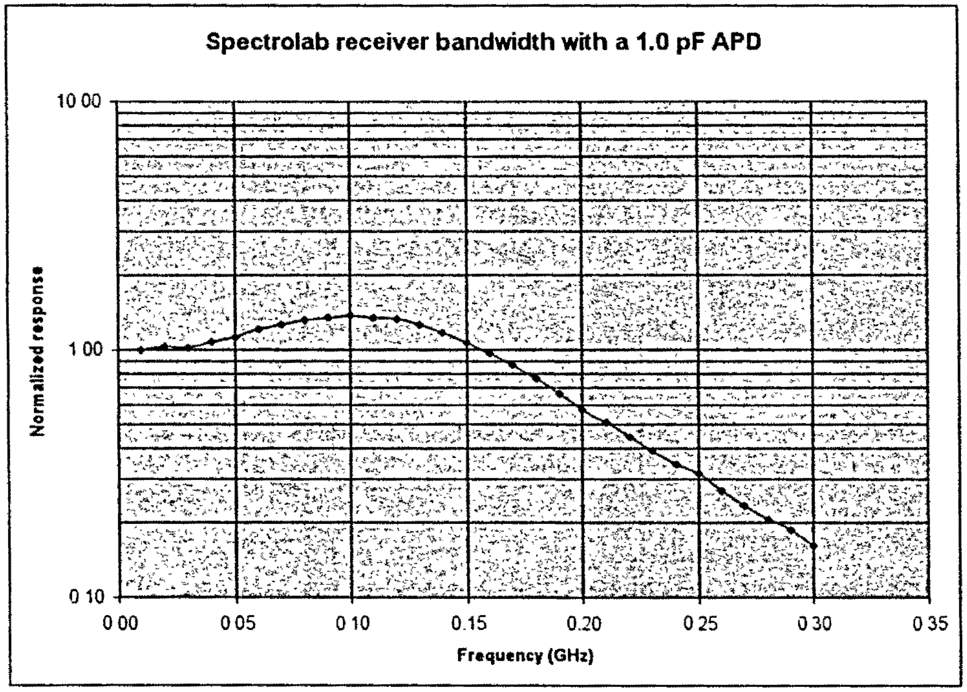
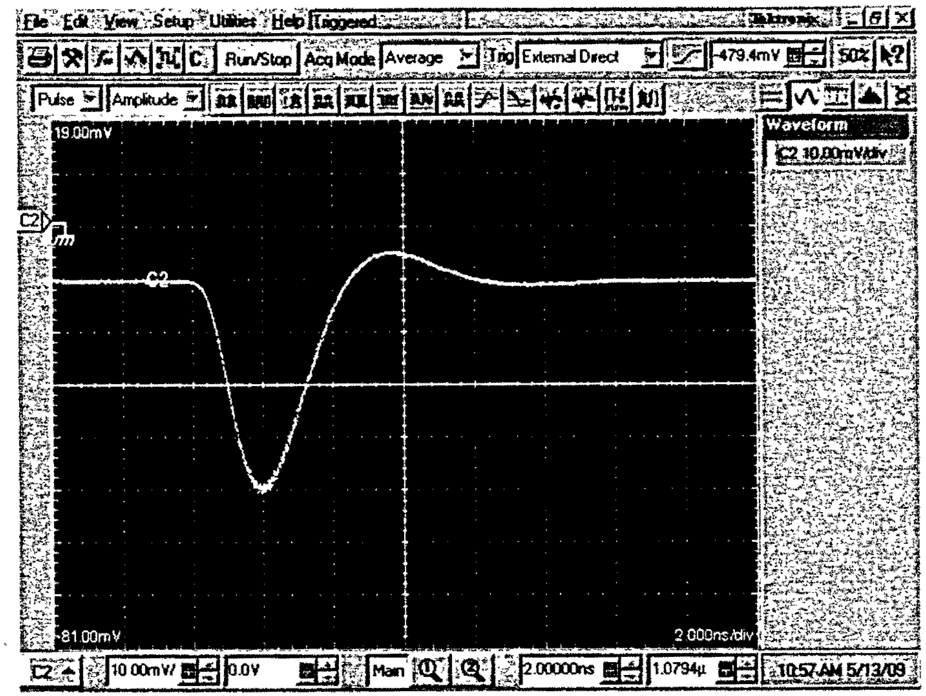
Receiver response to a 100ps 1.06μm laser pulse.

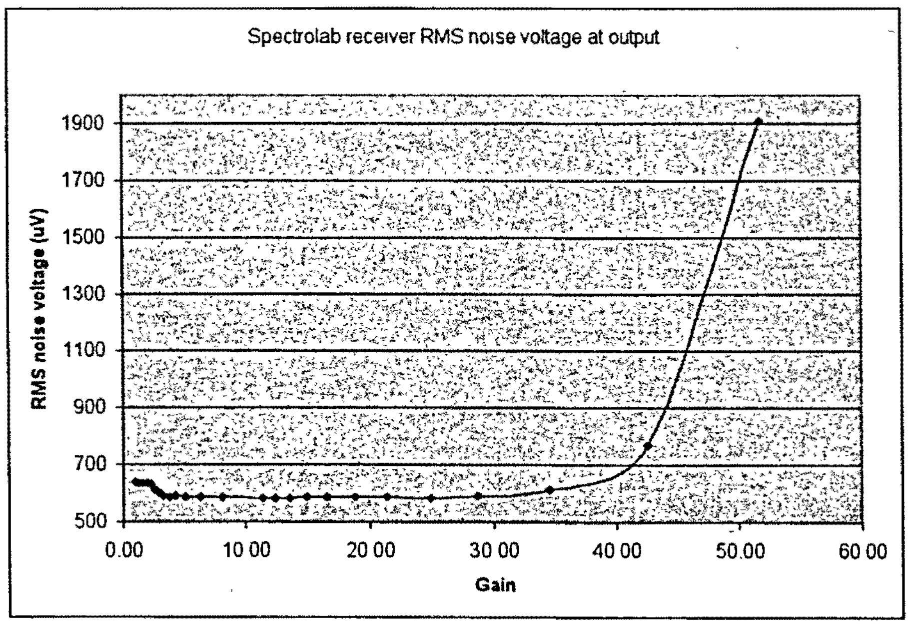




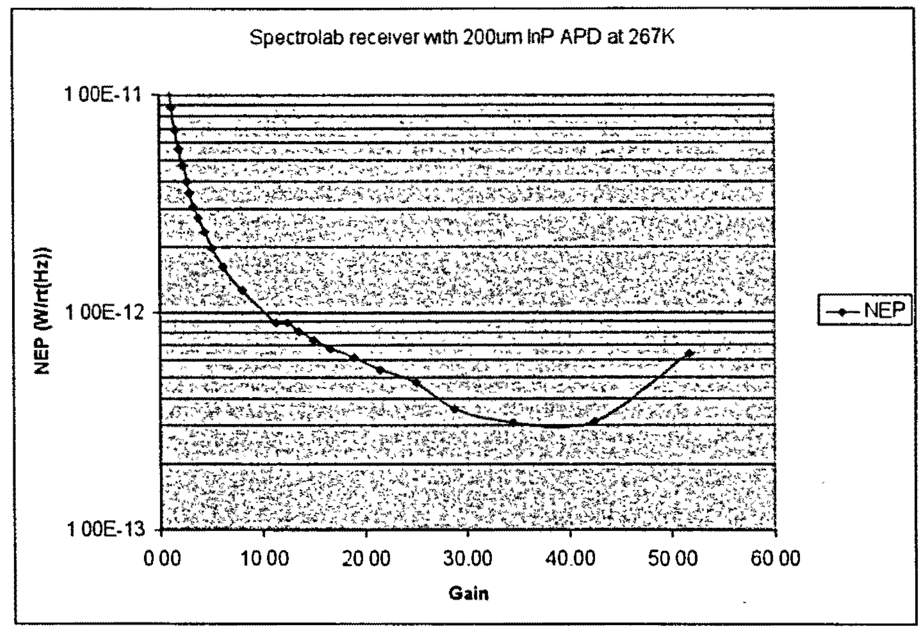
- **Achieved bandwidth of 180 MHz**

Gen. 1 Photoreceiver NEP Data

RMS Voltage Data



NEP Data



- **NEP < 300 fw/Hz$^{1/2}$ was achieved**

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Gen-2 Receiver Sensitivity Improvements

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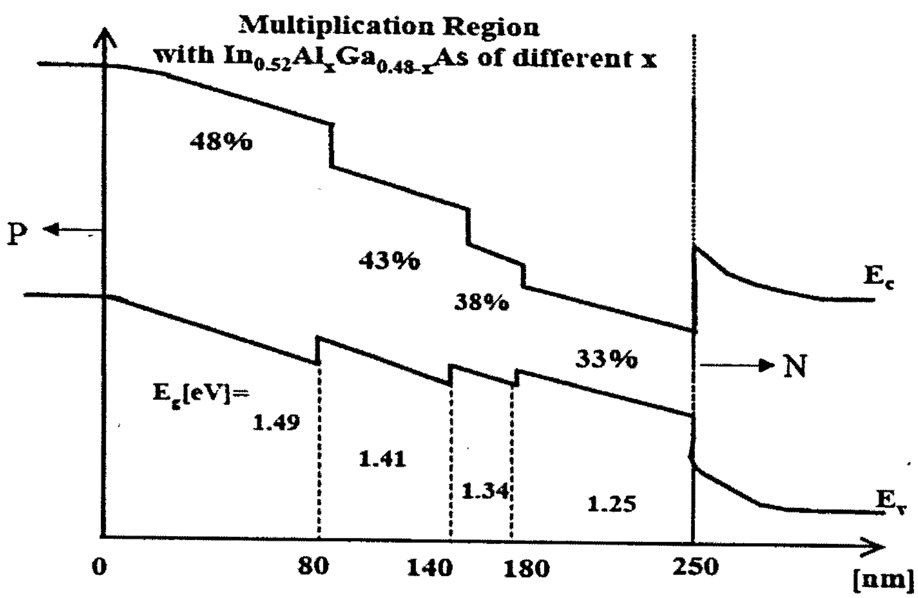
Goal: 300 fW/Hz$^{1/2}$ @ bandwidth of 1GHz

- Quantum efficiency
  - Gen. 1 InP APD has 64% quantum efficiency
  - 75% QE will reduce NEP by 17%.
- Low noise TIAs
  - Select best low noise TIAs in die form with less than 6pA/Hz$^{1/2}$ input referred noise current.
- Reduce excess noise in APD
  - InAlAs has a k value ~0.22
  - I^2E APD design with reduced $k_{eff} \leq 0.15$

I^2E APD Fundamentals

- APDs have high internal gain and associate excess noise
- k factor is a material parameter for bulk material

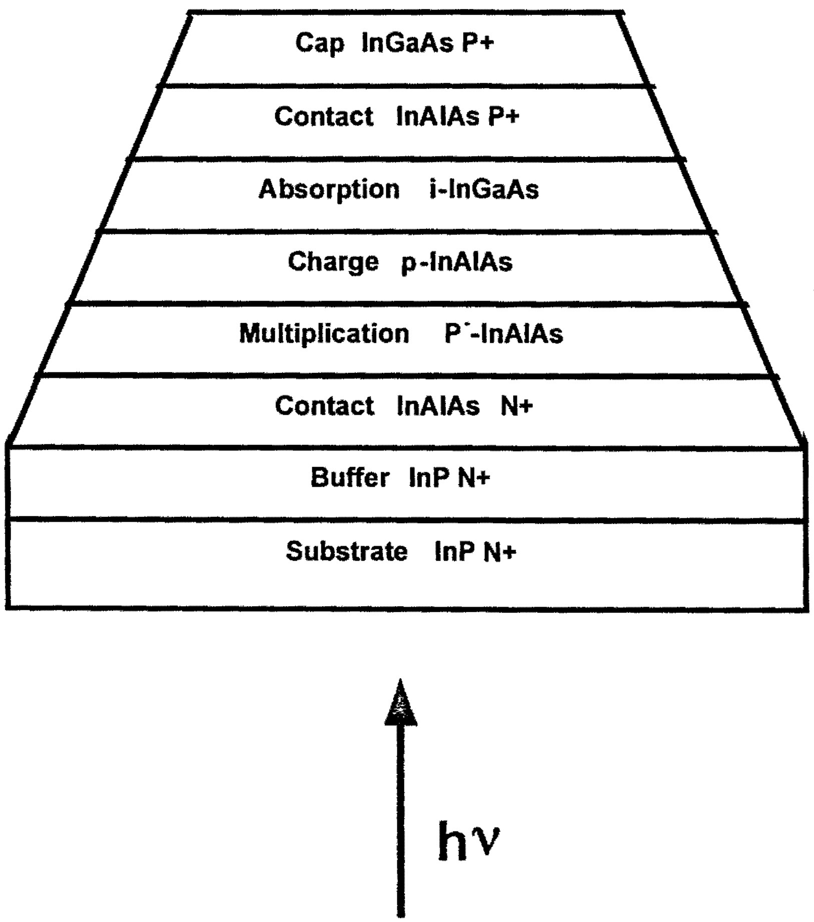
I^2E= Impact Ionization Engineering



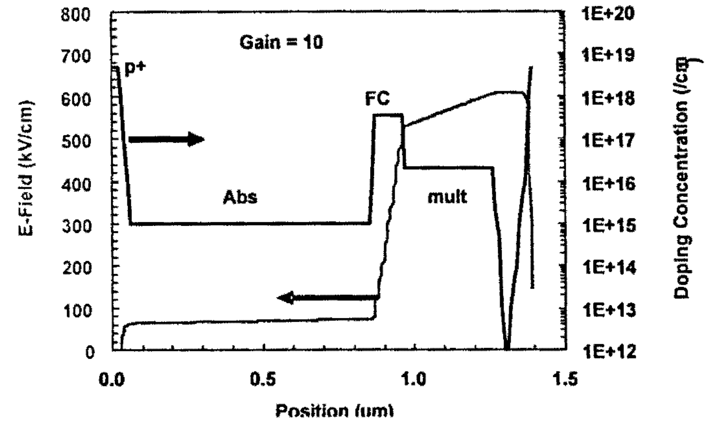
I^2E is an approach to combine materials with different impact ionization threshold energies in the multiplication region. In the I^2E structure, the avalanche events are more deterministic which result a low effective k-factor.

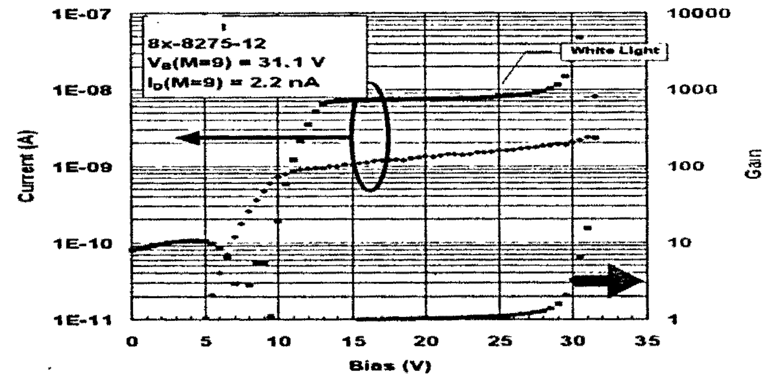
Graph from S. Wang, et. al., IEEE Photonics Technology Letters, Vol.14, No. 12, pg1722, 2002

Spectrolab InAlAs APD



InAlAs





InAlAs APD shows $k_{eff} = 0.22$

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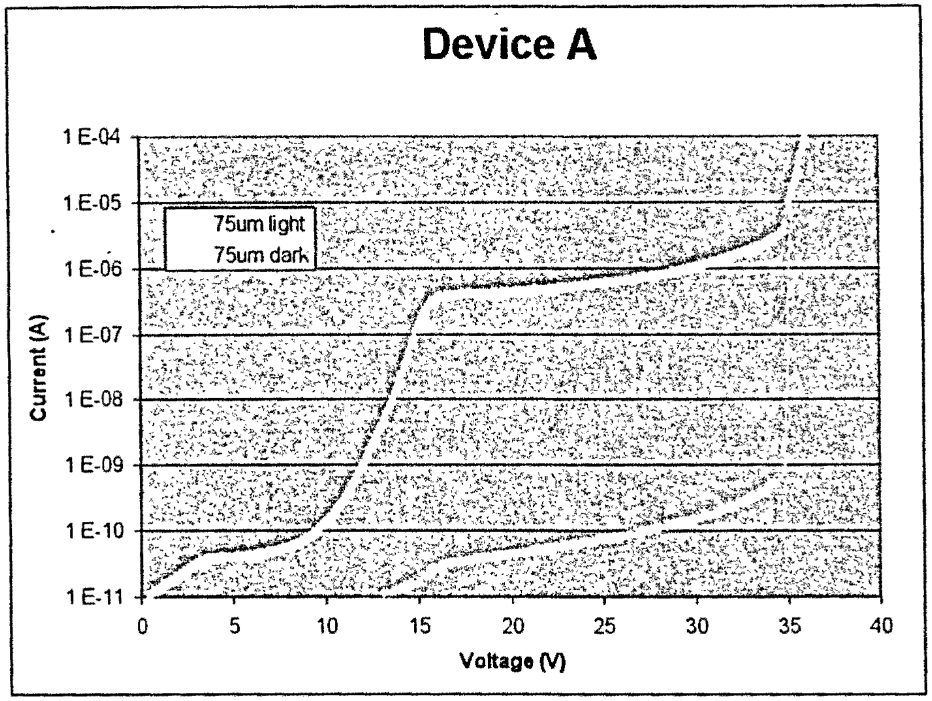
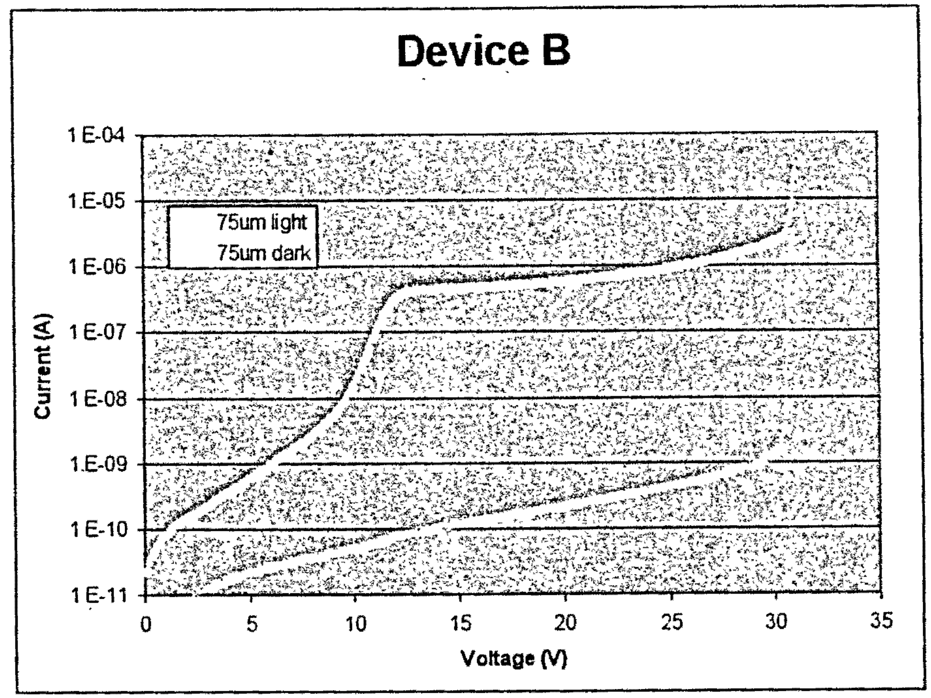
Spectrolab I^2E APD Design

p+ InGaAs Cap layer, 50nm
p+ InAlAs, 300nm
i-InGaAlAs Absorber 1200nm Eg~1.05 eV
p+, InAlAs Charge layer
I^2E Multiplier
n+ InAlAs Buffer
n+ InP Substrate

- InGaAlAs layer with bandgap of 1.2 eV is used as a multiplier

I^{2}E Device I-V Data





- **Show very low dark current before breakdown.**

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Excess Noise Measurement

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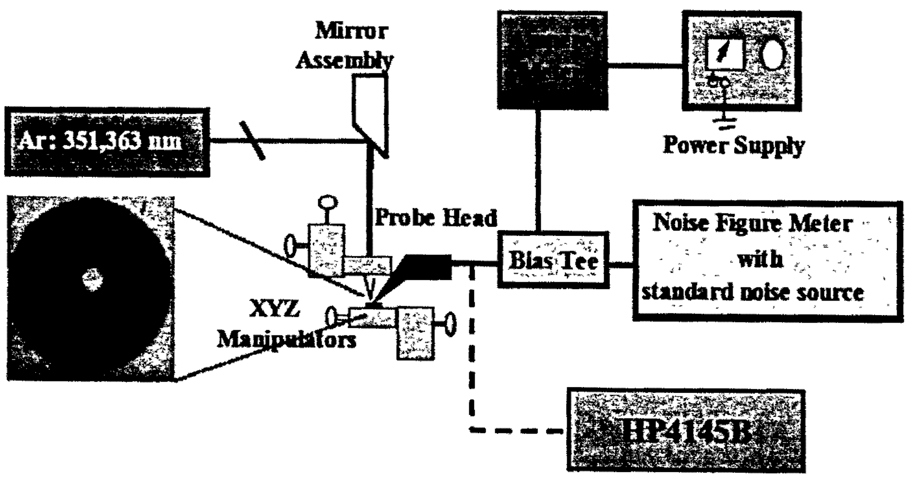

$$S = 2eI_{unity} M^2 F(M) R(\omega)$$

Testing procedure:

(a) At unity gain, measure S vs. I_{unity} to fit the 2eR(w).

(b) Measure S vs. M to get F(M).

UV laser is absorbed near the surface p+ contact layer.
Electrons are diffused into the multiplier, thus pure electron injection is realized.

* Setup graph is from Dr. Shuling Wang's Ph. D. dissertation(2002).

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Excess Noise Results

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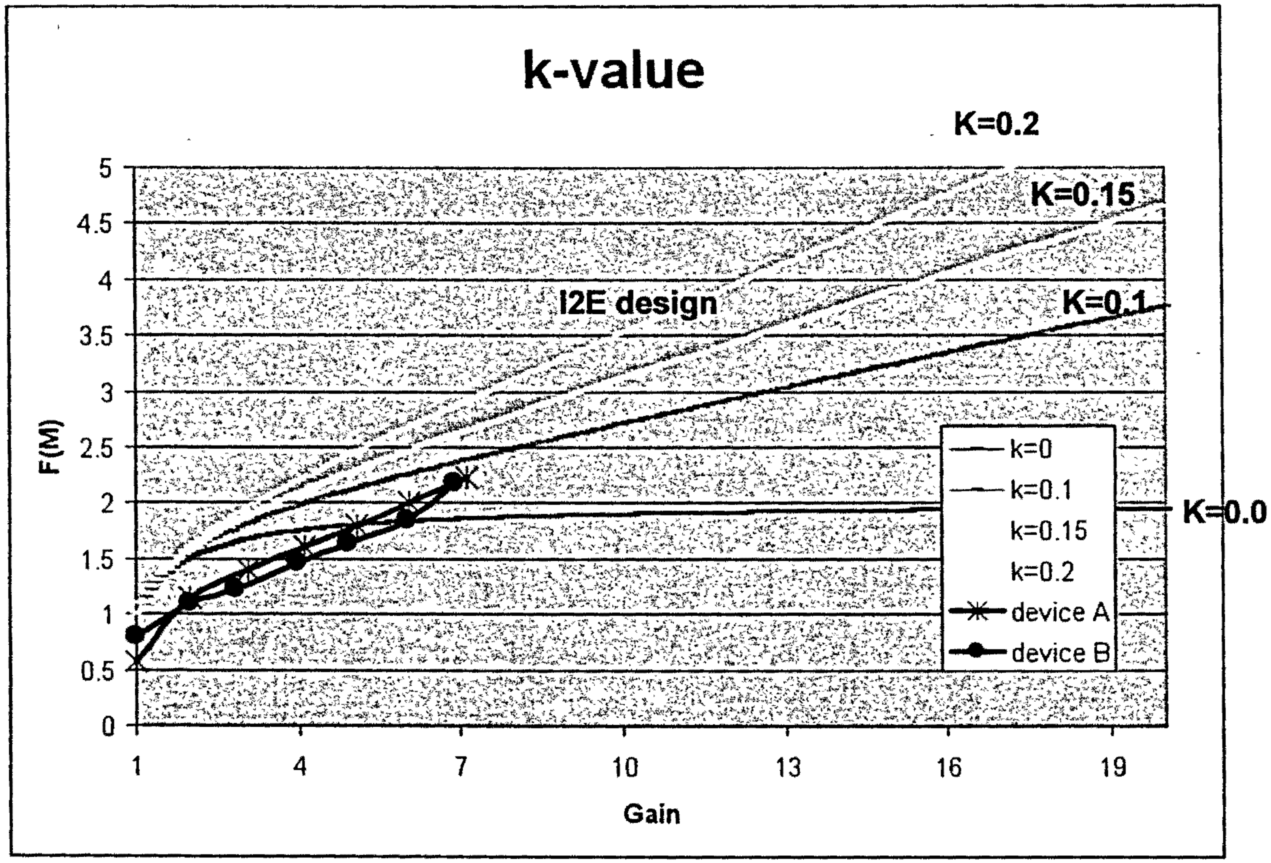
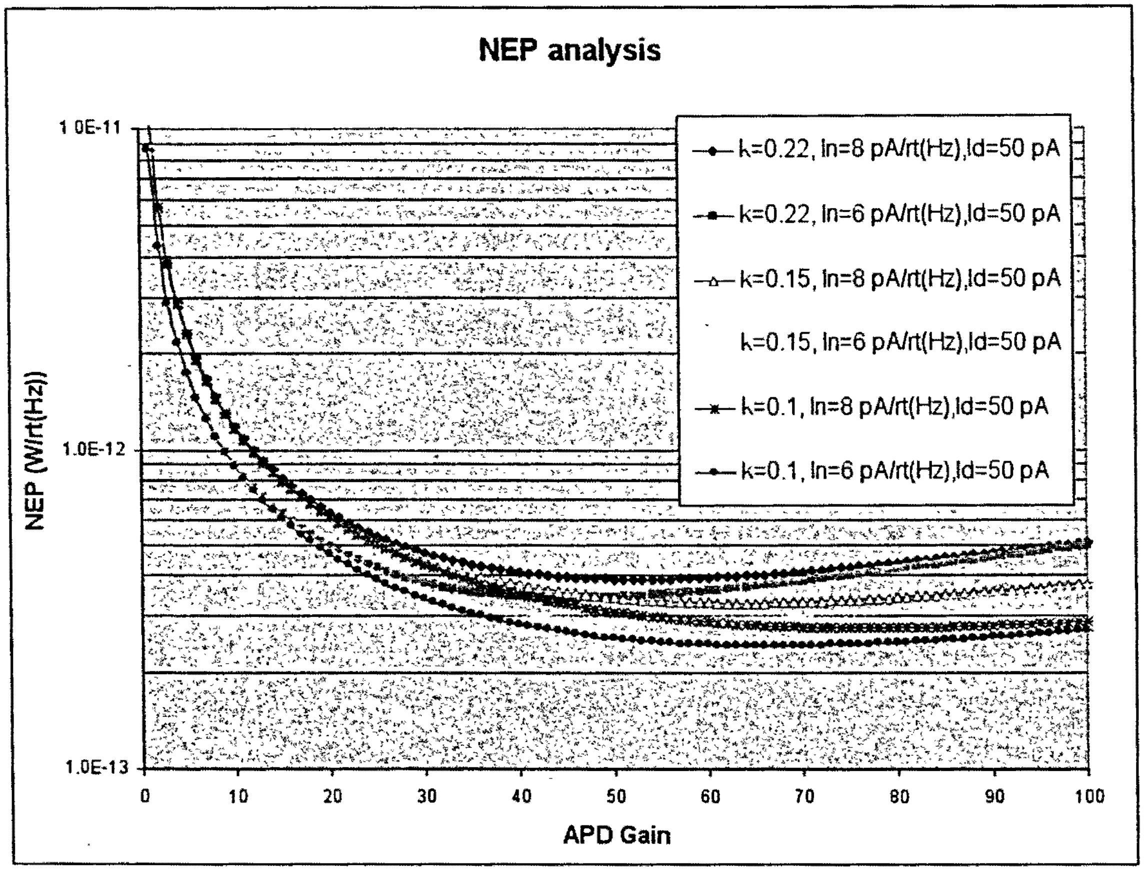


- Both device A and B show k value less than 0.1
- k≤0.15 is feasible at high gain (15~30) for future I^2E

Gen. 2 Photoreceiver – NEP Analysis



- **NEP less than 300 fW/Hz$^{1/2}$ over 1GHz bandwidth can be achieved using I^{2}E devices**

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Summary

- Demonstrated NEP<300fw/$Hz^{1/2}$ photoreceiver using InP APD
- Developed InAlAs based I^2E APDs
- Demonstrated low excess noise APDs, k_{eff}<0.1
- Developing Gen. 2 receiver with I^2E APD devices to achieve NEP less than 300fw/$Hz^{1/2}$ over 1 GHz